

Flame Arrester Evaluation for E-Diesel Fuel Tanks

September 3, 2002 – May 28, 2003

N. Weyandt and M.L. Janssens
Southwest Research Institute
San Antonio, Texas



NREL

National Renewable Energy Laboratory

1617 Cole Boulevard
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NREL Technical Monitor: R. McCormick

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ABSTRACT

An evaluation of various flame arresters for use with E-Diesel fuel (15% ethanol-diesel blend) was conducted on four diesel fuel tanks selected to represent typical fuel tank and fill neck designs. Multiple flame arresters were tested on each fuel tank for a total of thirteen test combinations. Testing was conducted at Southwest Research Institute's[®] (SwRI[®]) Department of Fire Technology from March 31, 2003 through April 24, 2003.

Tank No. 1 was a metal saddle type fuel tank with a 4-in. diameter, 3¹/₂-in. deep fill port (no fill neck). Tank No. 2 was a large plastic combine harvester fuel tank with a 2⁵/₈-in. diameter, 10-in. deep perforated brass fuel strainer inside a 4-in. fill neck. Tank No. 3 was a typical metal pickup truck fuel tank with a rubber fill neck having a 1⁷/₈-in. diameter opening, necked down to 1⁵/₈ in., and a total length of approximately 27 in. This fill neck also included a ⁵/₈-in. diameter rubber vent tube. Tank No. 4 was a large metal bus fuel tank with a 2-in. diameter, 12⁵/₈-in. long metal fill neck.

The flame arresting elements were selected by SwRI, and consisted of a single or multiple layers of wire mesh, or a round winding of stamped steel. Each flame arrester was installed in the fuel tank fill neck or fill mouth. An electric match was placed in the mouth of each fill neck, and the opening was sealed with a piece of clear, lightweight polyester. Blowout panels consisting of polyester sheets were placed in each fuel tank to prevent tank rupture. SwRI blended E-Diesel fuel in house to be used for this evaluation. The blend consisted of 84% No. 2 Diesel, 15% ethanol, and 1% of GE Betz DMX-10011 E-Diesel Blending Agent. Each fuel tank was filled between ¹/₄ and ¹/₂ of its rated capacity with the blended fuel.

The fuel tank was allowed to reach equilibrium vapor pressure at 72 ± 2°F, corresponding to a stoichiometric (or slightly rich) concentration of ethanol in air, representing a worst-case test scenario. After equilibrium was reached, ignition inside the fill neck or fill mouth was initiated by applying 9V across the electric match. Ignition was visually verified. The intent of the flame arrester was to stop flame propagation in the fill neck and prevent secondary ignition inside the fuel tank.

A series of five tests was conducted to assess the repeatability and durability of the systems. A flame arrester is considered to be successful if ignition within the fuel tank does not occur after a minimum of five consecutive tests. The flame arresters were inspected after each series of tests. Water was flowed through the flame arrester at 5 gallons per minute (gpm) to ensure that a reasonable flow could be achieved after successful ignition tests.

It was determined that wire mesh type flame arresters were insufficient for all tank and fill neck designs. Coarser meshes could not stop the propagation of flames, and the tighter meshes would deteriorate after being tested only a few times. The stamped steel flame arrester was found to be sufficient for all fuel tanks with the exception of Tank No. 1 (saddle fuel tank). This flame arrester consisted of 1¹/₄-in. wide strips of 0.004-in. (0.1 mm) thick stainless steel, stamped with a staggered triangular pattern and rolled into a cylinder of sufficient diameter to fill the fill neck. When the steel is rolled into a cylinder the maximum spacing through channels in the flame arrester was 0.08-in. (2.04 mm). This flame arrester allowed at least 5 gpm of flow without expulsion in all the fuel tank designs with the exception of Tank No. 1 (saddle fuel tank).

It was determined that none of the flame arresters would prevent ignition from propagating from the fill port into the fuel tank while still allowing fuel flow for the saddle tank. It may therefore be necessary to design a fill neck as an addition to saddle fuel tanks in order to install more effective flame arresters.

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Mr. Norm Marek of The State of Illinois Department of Commerce and Economic Opportunity, working with the Illinois Corn Marketing Board, provided SwRI with data on E-diesel blends and supplied the fuel tanks for use in the program.

Mr. Glenn V. Kenreck, P.E., of GE Specialty Materials provided the E-diesel blending agent as well as technical information on blending the fuel.

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1. INTRODUCTION

Development of renewable diesel blending components is desirable in order to displace imported petroleum and to reduce emissions of global warming gases. An important renewable diesel fuel is ethanol blended into diesel at up to 15 volume percent. This fuel is referred to as E-Diesel.

Ethanol and diesel are typically immiscible fluids due to their high molecular weight difference and the polarity of ethanol's alcohol group. Fuel additives must be added to facilitate mixing of the two fuels. Though apparently miscible with the additives, the ethanol and diesel in the blends retain their own vapor-liquid equilibrium characteristics. Therefore, at ambient temperatures, mainly ethanol resides in the headspace of E-Diesel blends. This makes the diesel fuel a Class I flammable liquid (upgraded from Class II combustible liquid for the original diesel fuel) when blended with ethanol. Therefore, the flammability properties of E-Diesel are a significant technical challenge from a safety standpoint.

At typical ambient temperatures (70 - 72°F), the vapor pressure of E-Diesel is 0.925 - 0.988 psi, which lies at ethanol's stoichiometric concentration in ambient air (6.5%). The flammable temperature range for ethanol once it has reached equilibrium inside a closed container (e.g. fuel tank) is approximately 51° - 106°F, based on flammability limits and vapor pressure data. The flammable temperature range at equilibrium in a closed container for diesel is approximately 148° - 302°F, and for gasoline is approximately 40° - 0° F. This shows that ethanol, and therefore E-Diesel, is most flammable over a more significant range of temperatures, posing a greater safety hazard in a closed container. The National Renewable Energy Laboratory, in collaboration with other agencies and industrial collaborators, has identified the low flash point and vehicle tank vapor flammability as the most important technical barriers to commercialization of E-diesel.

Few automotive manufacturers have shown interest in incorporating flame arresters in gasoline fuel tanks. Although ignition of the gasoline can easily occur at the mouth of the fill neck, it is virtually impossible for ignition to propagate down the fill pipe and into the fuel tank, since the fuel mixture is too rich (not enough oxygen). With ethanol fuel, however, ignition could easily propagate down a fill neck and into the fuel tank at typical ambient temperatures, causing the fuel tank to catastrophically fail.

2. OBJECTIVE

The objective of this research program was to determine through experimentation the type of flame arrester necessary to quench ignition on typical fuel tank and fill neck / fill mouth designs. A successful flame arrester must allow the passage of fuel during the refueling process, while not allowing the propagation of flames during a fire event.

3. APPROACH

3.1. General

Southwest Research Institute® (SwRI®) conducted this test program using fuel tanks and fill necks representative of standard design types and sizes in service. Flame arresting devices chosen by SwRI were placed in the fill neck or fill mouth of the fuel tanks. Each fuel tank was filled with the E-Diesel fuel and allowed to reach vapor / liquid equilibrium at $72 \pm 2^\circ\text{F}$. Vapors at the opening of the fill neck / fill mouth were ignited with an electric match, ignition in the fill neck / fill mouth was visually verified, and the fuel tank was observed for propagation.

3.2. Test Fuel

SwRI blended all fuel used in this evaluation in house. No. 2 Diesel and ethanol were obtained from Chevron Phillips Chemical Company LP, and were received on October 18, 2002. Certificates of Analysis were provided with the fuels (see Appendix A). The fuel additive was GE Betz DMX-10011 E-Diesel Blending Agent, received on November 11, 2002. The E-Diesel blend consisted of 84% No. 2 Diesel, 15% ethanol, and 1% of GE Betz DMX-10011 E-Diesel Blending Agent. The components were mixed together in fuel drums and mixed until a uniform solution appeared. The mixtures were observed, and separation did not occur.

3.3. Test Article Description

Four fuel tank / fill neck designs were used in this evaluation.

3.3.1. Tank No. 1

Tank No. 1 was a 63-gal capacity metal saddle fuel tank, typical of semi cabs. This design contained only a large fill mouth (no fill neck). The fill mouth was 3 $\frac{1}{2}$ in. deep with a 4-in. diameter. A rectangular hole in the top half of the flat side of the fuel tank was cut out and then sealed with a lightweight sheet of clear polyester to allow safe venting of combustion products. Internal components of the fuel tank (level indicator) were removed to prevent any projectiles during testing. The fuel tank was fitted with two Type K thermocouples to measure liquid and vapor temperatures inside the fuel tank to ensure a correct temperature range. An electric match was placed near the opening of the fill mouth, which was then covered with a sheet of polyester.

3.3.2. Tank No. 2

Tank No. 2 was a 250-gal capacity plastic fuel tank, from a combine harvester. This design contained a 4-in. fill neck, 1 $\frac{1}{8}$ in. deep. Below the fill neck, a 2 $\frac{5}{8}$ -in. diameter, 10-in. deep perforated brass fuel strainer was suspended for removal of particulates from fuel. A rectangular hole at the top of the fuel tank was cut out and then sealed with a lightweight sheet of clear polyester to allow safe venting of combustion products. Internal components of the fuel tank were removed to prevent any projectiles during testing. The fuel tank was fitted with two thermocouples to measure liquid and vapor temperatures inside the fuel tank to ensure a correct temperature range. An electric match was placed near the opening of the fill mouth, which was then covered with a sheet of polyester.

3.3.3. Tank No. 3

Tank No. 3 was a 25-gal capacity metal fuel tank, typical of personal pickup trucks. This design had a rubber fill neck (separate part connected to the fuel tank via hose clamp) having a 1 $\frac{7}{8}$ -in diameter opening, necked down to 1 $\frac{5}{8}$ in., and a total length of approximately 27 in. This fill neck also included a $\frac{5}{8}$ -in. diameter rubber vent tube. A rectangular hole at the top of the fuel tank was cut out and then sealed with a lightweight sheet of clear polyester to allow safe venting of combustion products; the opening for the sending unit was also covered with polyester for use as a second vent. No internal components were provided with the fuel tank. The fuel tank was fitted with two thermocouples to measure liquid and vapor temperatures inside the fuel tank to ensure a correct temperature range. An electric match was placed near the opening of the fill mouth, which was then covered with a sheet of polyester.

3.3.4. Tank No. 4

Tank No. 4 was a 118-gal capacity rectangular fuel tank, typical of buses. This design had a 2-in. diameter, 12 $\frac{5}{8}$ -in. long metal fill neck. In the side of the fill neck near the mouth was a smaller (1-in.) opening to allow venting during refueling. The fuel tank was long and sectioned off with stiffeners necessary for structural integrity. A rectangular hole at the top of the fuel tank was cut out

in each of the three sections and then sealed with a lightweight sheet of clear polyester to allow safe venting of combustion products. The fuel tank was fitted with two thermocouples to measure liquid and vapor temperatures inside the fuel tank to ensure a correct temperature range. An electric match was placed near the opening of the fill mouth, which was then covered with a sheet of polyester.

3.3.5. Fuel Tank Summary Table

Table 1. Fuel Tank Summary Table.

IDENTIFICATION	TYPE	CAPACITY	FILLNECK
Tank No. 1	Saddle	63 gal	4 in. dia, 3 ¹ / ₂ in. long*
Tank No. 2	Combine Harvester	250 gal	2 ⁵ / ₈ in. dia, 10 in. long
Tank No. 3	Pickup	25 gal	1 ⁵ / ₈ in. dia, 27 in. long
Tank No. 4	Bus	118 gal	2 in. dia, 12 ⁵ / ₈ in. long

*fill mouth only

3.4. Flame Arrester Components

The flame arrester designs evaluated were based on designs currently used on gasoline vehicles. The designs were modified in order to quench ethanol flame propagation. The first type of element used was stainless steel wire mesh (screen). Four sizes of wire mesh were used in this evaluation, referred to as Mesh A through Mesh D (from coarse to fine). The dimensions of the mesh are as follows:

Table 2. Wire Mesh Size Identification.

IDENTIFICATION	OPENING SIZE (ANGLE TO ANGLE)	THICKNESS
Mesh A (coarse)	0.1 in. (2.5 mm)	0.027 in. (0.68 mm)
Mesh B	0.05 in. (1.3 mm)	0.02 in. (0.5 mm)
Mesh C	0.05 in. (1.3 mm)	0.014 in. (0.35 mm)
Mesh D (fine)	0.0014 in. (0.04 mm)	0.0035 in. (0.09 mm)

The mesh was cut and fitted to completely cover the opening of the fill neck under test, allowing no gaps.

The second type of flame arrester element evaluated consisted of a round winding of stamped steel. The material was 0.004-in. (0.1 mm) thick stamped stainless steel in a 1¹/₄-in. wide strip. The stamp consisted of 0.04-in. deep triangular channels in a flattened “W” pattern running the entire 1¹/₄-in. thickness. When wound, the maximum spacing formed through the channels (angle to angle) was 0.08 in. (2.04 mm). The stamped steel was wound such that it filled the entire diameter of the fill neck under test.

3.5. Performance Criteria

The following performance criteria were evaluated visually during each test:

- The flame arrester must stop propagation of flames to the interior of the fuel tank.
- Ignition of fuel in the fill neck must occur on the exterior side of the flame arrester as verified by burning or expulsion of its polyester sheet.
- Ignition on the interior of the fuel tank must not occur as verified by no burning or expulsion of its polyester sheet, nor any other burning on the interior of the fuel tank (protected side of flame arrester).
- After a series of successful tests (typically five), ignition on the interior of the fuel tank tested was initiated with an electric match to verify a flammable concentration was present.
- Following ignition testing, flow testing of the flame arrester design was performed by flowing 5 gallons per minute (gpm) of water through the fill neck / flame arrester system. The test was considered successful if all the liquid was allowed to pass through the fill neck opening.

3.6. Test Procedure

The specific test procedure followed is listed below:

1. Fuel tank is prepared with blow out panels, thermocouples, flame arrester, fuel, and electric match as described in Section 3.2.
2. The fuel is allowed to reach equilibrium vapor pressure in the tank at $72 \pm 2^{\circ}\text{F}$.
3. Fuel tank is removed from the controlled environment and placed in the test area for immediate test.
4. Video documentation is initiated.
5. Test area is cleared and electric match is ignited remotely via a 9V source across a coaxial cable.
6. Any remaining fires are extinguished with CO_2 .
7. Flame arrester is inspected for damage.
8. Blow-out panels and electric matches are replaced.
9. If successful, procedure is repeated twice with a dry flame arrester and twice with a flame arrester wetted with E-Diesel fuel.
10. Once all tests are successful, the inside of the fuel tank is ignited remotely with an electric match.
11. Fires are extinguished with CO_2 .
12. Fill neck and flame arrester are tested for flow with water for at 5 gpm.

4. RESULTS

The flame arrester evaluation was conducted at SwRI's Department of Fire Technology located in San Antonio, Texas. These series of tests were conducted from March 31, 2003, through April 24, 2003. The test series are referred to as "X.X." The first X refers to the fuel tank number, and the second X refers to the flame arrester design number.

4.1. Saddle Fuel Tank

4.1.1. First Flame Arrester Design – Test Series 1.1

The first flame arrester design tested on the saddle fuel tank consisted of a single layer of Mesh C. The mesh was attached to the base of the fill mouth on the interior of the fuel tank such that it covered the entire opening at the innermost end. The flame arrester was unsuccessful in stopping the propagation of flames during the first test.

4.1.2. Second Flame Arrestor Design – Test Series 1.2

The second flame arrester design tested on the saddle fuel tank consisted of two layers of mesh. The mesh located on the exterior was Mesh C, and the interior was Mesh D (finest mesh). Both layers (C and D) were attached to the fill mouth on the interior of the fuel tank such that they covered the entire opening at the innermost end. The flame arrester configuration was able to stop the propagation of flames on the two initial tests, but was unsuccessful on the third consecutive test. Post-test observation of the third test showed the layer of Mesh D in poor condition due to repeated tests, likely contributing to failure.

A third design was not tested, since additional restrictions at the fill neck opening caused the expulsion of fuel at 5 gpm, making the designs impractical.

4.2. Combine Harvester Fuel Tank

4.2.1. First Flame Arrester Design – Test Series 2.1

The first flame arrester design tested on the combine harvester fuel tank consisted of the fuel strainer only. The fuel strainer was 0.04-in. thick brass shaped in a cylinder with 0.06-in. diameter perforations located around its entire dimensions. The fuel strainer by itself was unable to stop propagation of flames during the first test.

4.2.2. Second Flame Arrestor Design – Test Series 2.2

The second flame arrester design tested on the combine harvester fuel tank consisted of the same fuel strainer, and two layers of Mesh C. Both layers were located on the interior side of the fuel strainer. The composite flame arrester was unable to stop propagation of flames during the first test.

4.2.3. Third Flame Arrestor Design – Test Series 2.3

The third flame arrester design tested on the combine harvester fuel tank consisted of the fuel strainer, two layers of Mesh C, and two layers of Mesh D. The two layers of Mesh C were located on the interior side of the fuel strainer, and the two layers of Mesh D were located on the interior side of Mesh C. The flame arrester was able to stop the propagation of flames during the three initial tests, but was unsuccessful on the fourth consecutive test (first wetted condition test). Post-test observation after the third test showed the two layers of Mesh D in poor condition due to repeated tests, likely contributing to failure.

4.2.4. Fourth Flame Arrestor Design – Test Series 2.4

The fourth flame arrester design tested on the combine harvester fuel tank consisted of the fuel strainer, and a layer of the 1¹/₄-in. thick stamped steel located at the bottom of the strainer. The stamped steel was fit tightly such that it filled the entire diameter of the strainer. The perforations on the side of the strainer were covered with a single layer of aluminum foil tape (bottom perforations left open). The fourth design was able to stop the propagation of flames in five consecutive tests. Post-test observation found the flame arrester in good condition. The flame arrester located in the strainer was also able to flow 5 gpm of water without expulsion.

4.3. Pickup Fuel Tank

4.3.1. First Flame Arrestor Design – Test Series 3.1

The first flame arrester design tested on the pickup fuel tank consisted of a single layer of Mesh B only. The mesh was located in the rubber fill neck, next to the opening in the fuel tank, and was fixed such that it encompassed the entire diameter of the fill neck. The flame arrester was unable to stop propagation of flames during the first test.

4.3.2. Second Flame Arrestor Design – Test Series 3.2

The second flame arrester design tested on the pickup fuel tank consisted of a layer of the 1¹/₄-in. thick stamped steel. The flame arrester was located in the both the rubber fill neck and vent tube, next to the opening in the fuel tank. The second design was able to stop the propagation of flames in five consecutive tests. Post-test observation found the flame arrester in good condition. The flame arrester located in the fill neck was also able to flow 5 gpm of water without expulsion.

4.3.3. Third Flame Arrestor Design – Test Series 3.3

The third flame arrester design tested on the pickup fuel tank also consisted of a layer of the 1¹/₄-in. thick stamped steel. The flame arrester was located in the both the rubber fill neck and vent tube, halfway between the mouth of the fill neck and the fuel tank opening (approximately 13 in. down the fill neck). This design was identical to the Second design, with the exception that the flame arrester was located in a different position of the fill neck. The third design was able to stop the propagation of flames in five consecutive tests. Post-test observation found the flame arrester in good condition. The flame arrester located in the fill neck was also able to flow 5 gpm of water without expulsion.

4.4. Bus Fuel Tank

4.4.1. First Flame Arrestor Design – Test Series 4.1

The first flame arrester design tested on the bus fuel tank consisted of a single layer of Mesh B only. The mesh was located in the metal fill neck, next to the opening in the fuel tank. The mesh was fixed such that it encompassed the entire diameter of the fill neck. The flame arrester was unable to stop propagation of flames during the first test.

4.4.2. Second Flame Arrestor Design – Test Series 4.2

The second flame arrester design tested on the bus fuel tank consisted of seven layers of mesh. The layers were all located in the metal fill neck, next to the opening in the fuel tank. The layers were oriented as follows (closest to mouth of fill neck to closest to interior of fuel tank): Four layers of Mesh A, one layer of Mesh B, one layer of Mesh C, and one layer of Mesh D. The second design was able to stop the propagation of flames in five consecutive tests; however, the flame arrester was unable to flow 5 gpm of water without expulsion.

4.4.3. Third Flame Arrestor Design – Test Series 4.3

The third flame arrestor design tested on the bus fuel tank consisted of three layers of mesh (similar to second design, but with some layers removed for better flow). The layers were all located in the metal fill neck, next to the opening in the fuel tank. The layers were oriented as follows (closest to mouth of fill neck to closest to interior of fuel tank): One layer of Mesh B, one layer of Mesh C, and one layer of Mesh D. The third design was able to stop the propagation of flames in five consecutive tests. The flame arrestor located in the fill neck was also able to flow 5 gpm of water without expulsion. However, post-test observation found the flame arrestor in poor condition. It was apparent that additional tests would cause the flame arrestor to fail.

4.4.4. Fourth Flame Arrestor Design – Test Series 4.4

The fourth flame arrestor design tested on the bus fuel tank consisted of a layer of the 1 $\frac{1}{4}$ -in. thick stamped steel. The flame arrestor was located in the metal fill neck, next to the opening in the fuel tank. The fourth design was able to stop the propagation of flames in five consecutive tests. Post-test observation found the flame arrestor in good condition. The flame arrestor located in the fill neck was also able to flow 5 gpm of water without expulsion. However, fuel did back-up in the fill neck and the 1-in. vent opening located in the side of the fill neck had to be plugged to prevent the expulsion of liquid.

4.5. Post-Test Fuel Analysis

Post-test analysis of the E-diesel blend following the tests was performed to ensure the mixture still provided an explosive headspace of ethanol at ambient temperatures. It was expected that the ethanol content would have depleted during the testing due to its higher volatility than the other components. The ethanol content had depleted from a nominal 15% to 7.1%. However, the flash point remained near that of ethanol (E-diesel at 17°C, ethanol at 13°C), showing that the vapor of the mixture still had approximately the same properties as the mixture at the start of the program.

5. SUMMARY

It was determined that wire mesh type flame arresters were insufficient in all the tests conducted. Coarser meshes could not stop the propagation of flames, whereas the tighter meshes would deteriorate after being tested only a few times. Deterioration of the fine mesh is due to the fact that tighter meshes are typically constructed of finer gauge wire. A tighter mesh constructed of thicker gauge wire could theoretically stop the propagation of flames and retain its integrity, but fabrication of such mesh is most likely infeasible due to the nature of mesh (hole spacing is at least as large as wire gauge).

The stamped steel flame arrestor was determined to be sufficient for all fuel tanks with the exception of Tank No. 1 (saddle fuel tank). This flame arrestor consisted of 1 $\frac{1}{4}$ -in. wide strips of 0.004-in. (0.1 mm) thick stainless steel stamped with a staggered triangular pattern and rolled into a cylinder of sufficient diameter to fill the fill neck. When rolled the maximum spacing through channels in the flame arrestor were 0.08-in. (2.04 mm). This flame arrestor allowed at least 5 gpm of flow without expulsion in all fuel tank designs with the exception of Tank No. 1 (saddle fuel tank).

For the saddle tank, no flame arrestor was determined to prevent ignition from propagating from the fill port into the fuel tank while still allowing fuel flow. The saddle fuel tanks will most likely necessitate the addition of a fill neck (internal or external) in order to allow the installation of a sufficient flame arrestor.

The stamped metal type flame arresters determined to be sufficient in this evaluation are costly when compared to the wire mesh type flame arresters (estimated to be on the order of \$40 per

part vs. \$4 per part). It may prove more cost effective to evaluate additional wire mesh designs consisting of multiple layers. This would be a trial and error process to obtain a good balance of flame propagation mitigation and low flow resistance.

The results presented in this report are fairly limited in their scope, since only specific materials were tested. SwRI recommends follow-up work in order to expand the information available regarding E-diesel fuel flammability / explosibility, and the mitigation thereof. Additional fundamental properties of the fuel blend used in this study (15% ethanol in 84% No. 2 diesel with 1% GE Betz DMX-10011 E-Diesel Blending Agent) such as flame velocity, rate of pressure rise, and maximum pressures obtained inside different geometries should be determined. These same properties can then be determined for pure ethanol and other E-Diesel blends including those with No. 1 diesel and different blending agents. This research would provide information as to whether the blend studied was representative of pure ethanol or other blends, or whether each blend has to be field-tested in flame arresters independently.

SwRI also recommends the incorporation of blowout panels or other fast-acting pressure relief devices for use in E-Diesel fuel tanks. Blowout panels will allow the venting of combustion products without a catastrophic explosion of the fuel tank. Blowout panels would be unnecessary if a flame arrester is 100% effective in stopping propagation of flames into the fuel tank; however, it is possible that extreme conditions may arise that destroy the flame arrester or otherwise render it ineffective. A blowout panel would provide a reliable “last-resort” mechanism to relieve the pressure buildup on the inside of the fuel tank upon ignition, without a catastrophic explosion.

E-diesel fuel blends pose a much larger hazard from a fire-safety standpoint than diesel or gasoline, due to the fact that their vapors are most explosive at typical ambient temperatures. Safe onboard storage poses a significant technical challenge. However, we have shown that the use of properly sized flame arresters in fill necks help minimize these risks.

6. REFERENCES

1. NFPA 30, *Flammable and Combustible Liquids Code*, National Fire Protection Association, Quincy, Mass., 2000.
2. *Flammability Limits for Ethanol/Diesel Blends*, Final Report Prepared for Growmark, Inc., Battelle, September 30, 1998

APPENDIX A: FUEL CERTIFICATES OF ANALYSIS
(Consisting of 2 Pages)



DATE OF SHIPMENT
10-17-02

CUSTOMER PO NO.
241373G

SALES ORDER NO.
5615574

5 X 54 GALLON DRUM

MFG. DATE: 09-2002

CERTIFICATE OF ANALYSIS

DIESEL .05 LS CERT FUEL (# 2)
LOT 2HP05203

TESTS	RESULTS	SPECIFICATIONS	METHOD
Specific Gravity, 60/60	0.8455	0.8398 – 0.8654	ASTM D-4052
API Gravity	35.86	32 – 36	ASTM D-1298
Corrosion, 50°C, 3 hrs	1A	3 Max	ASTM D-130
Sulfur, ppm	365	300 – 500	ASTM D-2622
Flash Point, °F	156	130 Min	ASTM D-93
Pour Point, °F	-2	0 Max	ASTM D-97
Cloud Point, °F	-10	10 Max	ASTM D-2500
Viscosity, cs 40°C	2.4	2.2 – 3.2	ASTM D-445
Carbon wt%	86.8	Report	Phillips
Hydrogen wt%	13.17	Report	Phillips
Carbon Density (gm/gal)	2773	2750 – 2806	Calculated
Net Heat of Combustion BTU/LB	18448	Report	ASTM D-3338
Particulate Matter (mg/l)	3.5	15 Max	ASTM D-2276
Cetane Index	48.0	40 – 48	ASTM D-976
Cetane Number	46.8	40 – 48	ASTM D-613
			ASTM D-86
DISTILLATION, °F			
IBP	375.2	340 – 400	
5%	407.5		
10%	428.5	400 – 460	
20%	455.7		
30%	475.5		
40%	492.1		
50%	506.9	470 – 540	
60%	522.4		
70%	538.6		
80%	558.3		
90%	585.3	560 – 630	
95%	607.6		
EP	633.8	610 – 690	
Loss	0.5		
Residue	1.0		
			ASTM D-1319
HYDROCARBON TYPE, VOL%			
Aromatics	31	28 – 31	
Olafins	2.6	Report	
Saturates	66.4	Report	

D.G. Doerr tek

D.G. Doerr
Fuels Unit Team Leader

DGD: clg
10/17/02

Figure 1. Diesel Analysis.



DATE OF SHIPMENT
10-17-02

CUSTOMER PO NO.
241373G

SALES ORDER NO.
5615574

1 X 54 GALLON DRUM

MFG DATE: 10-2002

CERTIFICATE OF ANALYSIS

ETHANOL
Lot 2EPEOH01

<u>Tests</u>	<u>Results</u>	<u>Specifications</u>	<u>Method</u>
Specific Gravity 60/60	0.7959	Report	ASTM D-4052
API Gravity	46.29	Report	ASTM D-1298
Existent Gums (mg/100ml)(washed)	0.6	5 Max	ASTM D-381
<u>Distillation, °F</u>			<u>ASTM D-86</u>
IBP	171.1	Report	
5%	172.3		
10	172.6		
20	172.8		
30	172.9		
40	172.9		
50	172.9		
60	172.9		
70	173.1		
80	173.1		
90	173.3		
95	173.8		
EP	192.9		
Loss	0.5		
Residue	0.6		
<u>Composition, Vol%</u>			<u>ASTM D-1744</u>
Fischer Water	1.0		
Ethanol	97.79	95 Min	
Hydrocarbon	2.21		

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Fuels Unit Team Leader

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10/17/02

Figure 2. Ethanol Analysis.

APPENDIX B: PHOTOGRAPHIC DOCUMENTATION
(Consisting of 8 Pages)



Figure B-1. Tank No. 1 – Overall Setup.



Figure B-2. Tank No. 1 – Internal View of Screen-Type Flame Arrester.



Figure B-3. Tank No. 1 After Typical Flame Arrester Failure.



Figure B-4. Tank No. 2 After Typical Flame Arrester Pass.



Figure B-5. Tank No. 2 Overall Setup.



Figure B-6. Brass Fuel Strainer (Test 2.1).



Figure B-7. Brass Fuel Strainer Next to Stamped Steel Flame Arrester (Test 2.4).



Figure B-8. Brass Fuel Strainer with Stamped Steel Flame Arrester Installed (Test 2.4).



Figure B-9. Tank No. 3 Overall Setup.



Figure B-10. Tank No. 3 Fill Neck Mouth Shown Prior to Test with Electric Match Installed.



Figure B-11. Tank No. 3 Fill Neck with Stamped Metal Flame Arrester Installed (Test No. 3.2).



Figure B-12. Tank No. 3 Vent Tube with Stamped Metal Flame Arrester Installed (Test No. 3.2).



Figure B-13. Tank No. 4 Overall Setup.



Figure B-14. Fill Neck Removed From Tank No. 4 – Screen Type Flame Arrester Shown (Test 4.2).



Figure B-15. Tank No. 4 After Typical Failure.

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